The Herpetological Bulletin 170, 2024: 19–22
RESEARCH ARTICLE

https://doi.org/10.33256/hb170.1922

The effects of commercial diets on the growth of diamondback terrapins *Malaclemys terrapin* in head-start programmes

COURTNEY PARKS[1], BETHANY HOLTZ[1], JONATHAN FINGERUT[1], JOHN WNEK[2] & SCOTT MCROBERT[1*]

[1]Department of Biology, Saint Joseph University, 5600 City Ave, Philadelphia, PA 19131
[2]Marine Academy of Technology and Environmental Science (MATES), 195 Cedar Bridge Road, Manahawkin, NJ 08050

[*]Corresponding author e-mail: smcrober@sju.edu

ABSTRACT – Populations of diamondback terrapins *Malaclemys terrapin* are declining. Consequently, head-start programmes, in which hatchling terrapins are reared in captivity for 6–9 months and then released into their natural habitat, are needed to help stabilise wild populations. As a contribution to the development of optimal husbandry conditions for future generations of diamondback terrapins in head-start programmes, we examined the effects of two widely available commercial turtle foods (Reptomin® and Mazuri®) on the growth of juvenile terrapins over a period of 12 weeks. While terrapins did well on both diets, we show that terrapins consuming the Mazuri® diet had a significantly greater increase in mass and carapace length compared to terrapins on the Reptomin® diet.

INTRODUCTION

Diamondback terrapins *Malaclemys terrapin* are a brackish-water species found along the eastern and Gulf coasts of the United States. Considered a keystone predator regulating species that can degrade habitats such as the periwinkle snail *Littorinidae littorea* (Silliman & Bertness, 2002), they are also a bioindicator of environmental levels of mercury and other toxins (Basile et al., 2011; Blanvillain et al., 2007). Unfortunately, terrapin populations have suffered declines due to pressures from the food and pet trades, residential development, vehicle interactions and climate change (Gibbons et al., 2001; Rowe et al., 2020; Szerlag-Egger & McRobert, 2007; Wood, 1997; Woodland et al., 2017) and are listed as Vulnerable by the International Union for the Conservation of Nature (IUCN, 2024). To mitigate this decline, conservation efforts have been initiated to limit losses, including laws to limit collection, mandating crab-trap excluders, the installation of traffic barriers and the establishment of nesting sites.

As an additional conservation effort, there are head-start programmes that involve rearing hatchlings in captivity before releasing them into the wild (Gibbons et al., 2001; Haskell et al., 1996). In captivity, juvenile terrapins are not exposed to environmental stressors such as predators and so can direct more metabolic energy into growth (Koper & Brooks, 2000; Holliday et al., 2009). When released these larger terrapins may have a better chance of surviving the harsh conditions of the wild and will thus strengthen wild populations.

In 1989, Richard Stockton College (now Stockton University) initiated a long-term head-start programme for terrapins in southern New Jersey, USA (Herlands et al., 2004). This current study utilised hatchlings from this programme to examine the effects of diet on captive growth rates.

MATERIALS & METHODS

Hatchling collection

In August and September 2021, *M. terrapin* hatchlings were collected as part of a conservation project at the Long Beach Township Marine Field Station, NJ. The hatchlings were transported to the Biodiversity Laboratory at Saint Joseph's University, Philadelphia, Pennsylvania, USA, in 1.5L plastic containers with 2.5 cm depth of fresh water.

Housing

After arriving at SJU's Biodiversity Laboratory, hatchlings were randomly assorted into tanks, and marked with dots on their carapaces for identification purposes using non-toxic nail polish (L.A. Colors®, Fresh Paint® and Wet n Wild®). These markings were refreshed when needed, and no damage was observed to the carapace scutes from the markings.

All hatchlings were initially housed in glass aquaria with fresh water to become acclimated to the lab, and begin eating regularly. When the experiment began, hatchlings were moved into aquaria in groups of four. Water depths started at approximately 5 cm and were increased as the hatchlings grew. During the 12-week experimental period, a swimming space of 74,331 cm^3 (45.72 x 91.44 x 17.78 cm) was maintained in all tanks, with a basking area (bricks) of 869.35 cm^2. Lighting was provided by 60-watt incandescent bulbs with aluminium reflectors. Two lights were placed over the basking areas within each tank, and maintained on a 12:12 LD cycle, switching on at 08:00 h EST each day. UVB lighting was not provided during the trial period (see Discussion). Filtration was provided initially by small internal filters (Aqueon) but changed to external filters (Whisper) when the water depth was increased. Filter material was cleaned weekly and tank water was replaced biweekly to maintain water quality. Room and water temperature were maintained at 22–26 °C.

Table 1. Guaranteed analyses of the Reptomin® and Mazuri® diets

Guaranteed Analysis	Reptomin®	Mazuri®
Crude protein, min	42.5%	40.0%
Crude fat, min	8.5%	10.0%
Crude fibre, max	2.0%	5.00%
Moisture, max	8.0%	12.0%
Ash, max	Not reported	9.50%
Calcium (Ca), min	2.0%	1.85%
Calcium (Ca), max	Not reported	2.35%
Phosphorus (P), min	1.8%	1.00%
Sodium (Na), min	Not reported	0.55%
Vitamin E, min	Not reported	250 IU/kg
Ascorbic acid (vitamin C), min	100 mg/kg	Not reported

Table 2. Comparison of ingredients listed for the Reptomin® and Mazuri® diets

Reptomin ®	Reptomin ® & Mazuri ®	Mazuri ®
Wheat starch	Fresh meal	Ground corn
Corn flour	Dried yeast	Corn gluten meal
Shrimp meal	Dehulled soybean meal	Chicken meal
Wheat gluten	L-Ascorbyl-2-Polyphosphate (Vitamin C)	Porcine meat and bone meal
Potato protein	D-Calcium	Fish oil
Soybean oil	Pantothenate	Salt
Monobasic calcium	A-Tocopherol- Acetate (Vitamin E)	Calcium iodate
Phosphate	Thiamine mononitrate (B1)	Biotin
L-Lysine monohydrochloride	Pyridoxine	Choline chloride
Lecithin	Hydrochloride (B6)	Magnesium oxide
Algae meal ascorbic acid (Vitamin C)	Menadione sodium	Riboflavin supplement
D-Calcium pantothenate	Bisulfite (Vitamin K)	Vitamin A acetate
Vitamin A palmitate	Zinc sulfate	Zinc oxide
Manganese sulfate monohydrate	Cholecalciferol (D3) (Vitamin D3 supplement)	Cobalt carbonate
Ferrous sulfate monohydrate	-	Nicotinic acid
Cobalt acetate	-	Copper sulfate
Food Colour: Beta-carotene, blue 2 lake, and yellow lake	-	DL-Methionine sodium selenite

Diet protocol

In the Autumn of 2021, 20 hatchlings were divided into two diet groups. Hatchlings were divided randomly based on the mixing of two different clutches to minimise clutch effect. One group (8 terrapins, housed in two tanks, in groups of four) was fed Reptomin® Floating Food Sticks (Tetra) while the other (12 terrapins, housed in three tanks, in groups of four) was fed Aquatic Turtle Diet (Mazuri®). Table 1 shows the nutritional content of each food and Table 2 provides a comparison of the composition of both feeds. Food was measured before feeding with a top-loading electronic scale (Ohaus CS 200; + 0.1 g) and provided to each group Monday–Saturday, ad libitum. After allowing the hatchlings to eat for an hour, the excess food was removed by siphoning the water through netting and allowing it to dry. The dry food was weighed the next day. Each hatchling was measured biweekly with a digital caliper (+ 0.1 mm) for carapace straight length (CSL); the measurement from the nuchal to the pygal scute of the carapace in a straight line. Mass was measured biweekly.

Statistical methods

CSL and mass were compared between diet groups using 2-tailed independent sample t-tests (IBM SPSS Statistics Subscription for Microsoft Windows 64-bit). Tests were run to ensure the groups met the assumptions for heteroskedasticity (Levene's Test) and normality (Shapiro-Wilk Test). Data were found to be normal in all tests, however the change in carapace and mass showed significant differences in variance so that the two-sample t-test for unequal variance was required when comparing treatment groups for both parameters. To account for the family-wise error rate resulting from multiple tests of the same treatments for different hypotheses (parameters) we used the Bonferroni p value correction for multiple tests (α/n where alpha is the chosen significance level and n is the number of hypotheses tested) to determine significance of each test. Finally, the same independent sample t-test was used to compare the amount of food consumed in both treatments.

RESULTS

There were no statistically significant differences with respect to initial mass across terrapins from each diet group (Reptomin: 45.8 ± 2.87 g vs. Mazuri: 50.02 ± 5.6 g; t-test for equal variance, $t_{15.84} = -0.68$, p = 0.508). Likewise there were no significant differences with respect to initial CSL across terrapins from each diet group (Reptomin: 59.6 ± 1.52 mm vs. Mazuri: 59.33 ± 2.7 mm, t-test for equal variance, $t_{16.54} = 0.09$, p = 0.926).

With respect to growth, terrapins that were fed Mazuri® showed a significantly greater change in mass than terrapins fed Reptomin® (Reptomin: 64.8 ± 2.14 g vs. Mazuri: 98.0 ± 5.95 g, t-test for equal variance, $t_{13.7} = -5.26$, $p < 0.001$). Terrapins that were fed Mazuri® also showed a significantly greater change in CSL than terrapins fed Reptomin® (Reptomin: 21.7 ± 1.03 mm vs. Mazuri: 28.9 ± 0.91 mm, t-test for equal variance, $t_{16.1} = -5.23$, $p < 0.001$).

There was no statistically significant difference in the amount of food consumed by terrapins in the two diet groups (Reptomin: 25.6 g ± 2.0 vs. Mazuri: 34.0 g ± 5.54. independent samples t-test, $t_3 = -1.147$, p = 0.335).

DISCUSSION

This study presents a comparison of two commercial turtle foods (Reptomin® and Mazuri®), utilised in a diamondback terrapin head-start programme. During a 12-week period (within the 6-9 months the terrapins were maintained in captivity), we determined that Mazuri® led to a significantly greater increase in both CSL and mass.

One potential limitation to these findings was the use of incandescent lighting, rather than lights providing UVB radiation that are essential to vitamin D3 synthesis in reptiles (see Acierno et al., 2006). Vitamin D3, in turn, is crucial to calcium metabolism. In captive settings reptiles without UVB lighting may require dietary supplementation of calcium and vitamin D3. Analysis of the Reptomin® and Mazuri® diets (Tables 1 and 2) show that they contain similar amounts of calcium, and both contain vitamin D3 (although the amounts are not specified). During our study we did not note any clinical signs of D3 or calcium deficiency (such as deformed or soft shells), but we recognise this as a limitation and plan to use UVB lights in the next phase of this study.

Another potential limitation was housing our terrapins in groups of four, which may lead to competition for food and space, and the possibility of aggression. Our stocking density was 18,582.8 cm^3 swimming space/terrapin, and 217.34 cm^2 basking space/terrapin. We regularly examined each terrapin, and found no signs of aggression (wounds), and excess food was collected after each feeding, assuring that each terrapin had enough to eat.

Reptomin® has a higher percentage of crude protein, while Mazuri® has a higher percentage of crude fat and crude fibre. In terms of protein sources, both diets have fish and dehulled soybean meal. Mazuri® also includes chicken meal, porcine meat, bone meal and fish oil, while Reptomin® includes shrimp meal and potato protein. It has been shown that juvenile slider turtles *Trachemys scripta* fed diets with 25% or 40% crude protein grew significantly faster than turtles receiving a diet with only 10% crude protein (Avery et al., 1993). However, the diets used in our study both had at least 40% crude protein. Another noteworthy ingredient was biotin, which has been shown to increase keratin production, possibly affecting the growth of hair, bone and shell (da Silva et al., 2010). Although we did not measure the levels of biotin (only listed as an ingredient in the Mazuri® diet) within the hatchling's shells, it is possible that this improved CSL growth for the Mazuri® group.

While head-start programmes have been shown to help terrapins avoid many of the issues they face during early life stages, the approach is controversial. There is concern that head-start hatchlings may outcompete wild hatchlings because of their enhanced size. Since size is associated with age (Gibbons & Semlitsch, 1982; Haskell et al., 1996) there are additional concerns of ageing hatchlings faster. In fact, hatchlings in head-start programmes have been noted to be the size of 2–3-year-old juveniles in the wild (Holliday et al., 2009; Rowe, 2018; Ashley et al., 2021). Successful head-start terrapins could, in theory, go on to produce the next generation faster than terrapins that were not in head-start programmes. Growing at a faster rate may result in the hatchlings being sexually mature earlier which raises concerns of limiting genetic diversity, which can result in inbreeding, and other genetic complications (Dodd & Seigel, 1991; Frankham, 2005).

Comparisons of captive growth rates for terrapins, while important, can be limited by differences in experimental methodologies. For instance, Holliday et al. (2009) studying *M. terrapin* show notable differences in final terrapin sizes when compared to our study. However, in their study, the terrapin hatchlings where exposed to toxins (PCB) and/or different levels of salinity, their treatments began eight months after terrapin hatchlings emerged from eggs, their terrapins were housed individually, and fed a different diet (frozen brine shrimp). Our terrapins were raised in groups of four, in fresh water and under incandescent lights. It is likely that these differences in methodology are responsible for the differences in terrapin sizes across the two studies.

In summary, despite their potential disadvantages, head-start programmes may be one of the best tools to help stabilise declining populations of turtles. The adoption of better husbandry techniques, including potentially better diets as described in this study, can help to improve the efficiency of head-start programmes.

ACKNOWLEDGEMENTS

We would like to thank Michele Budd from Project Terrapin and the Terrapin Nesting Project, as well as the Long Beach Township Field Station for providing terrapin hatchlings for the project, and for releasing the yearlings after the study. In addition, we would like to thank Project Terrapin for its support and collaboration under NJ Scientific Holding Permit (#2021-019), NJ Fish and Wildlife (#2021-091), along with Saint Joseph University for facility usage. We thank Gigi Hess, Lauren Schnell, Madison Difonzo for feeding, maintaining and measuring the hatchlings. We would like to thank our reviewer, Dr Chris Michaels, for his knowledge, insightful comments and constructive guidance, which significantly contributed to improving this manuscript.

REFERENCES

Acierno, M.J., Mitchell, M.A., Roundtree, M.K. & Zachariah, T.T. (2006). Effects of ultraviolet radiation on 25-hydroxyvitamin D3 synthesis in red-eared slider turtles (*Trachemys scripta elegans*). *American Journal of Veterinary Research* 67(12): 2046–2049.

Ashley, E.A., Davis, A.K., Terrell, V.K., Lake, C., Carden, C., Head, L., Choe, R. & Maerz, J.C. (2021). Effects of salinity on hatchling diamond-backed terrapin (*Malaclemys terrapin*) growth, behavior, and stress physiology. *Herpetologica* 77(1): 45–55.

Avery, H.W., Spotila, J.R., Congdon, J.D., Fischer Jr, R.U., Standora, E.A. & Avery, S.B. (1993). Roles of diet protein and temperature in the growth and nutritional energetics of juvenile slider turtles, *Trachemys scripta*. *Physiological Zoology* 66(6): 902–925.

Basile, E.R., Avery, H.W., Bien, W.F. & Keller, J.M. (2011). Diamondback terrapins as indicator species of persistent organic pollutants: using Barnegat Bay, New Jersey as a case study. *Chemosphere* 82(1): 137–144.

Blanvillain, G., Schwenter, J.A., Day, R.D., Point, D., Christopher, S.J., Roumillat, W.A. & Owens, D.W. (2007). Diamondback terrapins, *Malaclemys terrapin*, as a sentinel species for monitoring mercury pollution of estuarine systems in South Carolina and Georgia, USA. *Environmental Toxicology and Chemistry: An International Journal* 26(7): 1441–1450.

da Silva, L.A., Franco, L.G., Atayde, I.B., da Cunha, P.H., de Moura, M.I. & Goulart, D.S. (2010). Effect of biotin supplementation on claw horn growth in young, clinically healthy cattle. *The Canadian Veterinary Journal* 51(6): 607–610.

Dodd, C.K. & Seigel, R.A. (1991). Relocation, repatriation, and translocation of amphibians and reptiles: are they conservation strategies that work? *Herpetologica* 47: 336–350.

Frankham, R. (2005). Genetics and extinction. *Biological Conservation* 126: 131–140.

Gibbons, J.W. & Semlitsch, R.D. (1982). Survivorship and longevity of a long-lived vertebrate species: how long do turtles live? *Journal of Animal Ecology* 51: 523–527.

Gibbons, J.W., Lovich, J., Tucker, A.D., FitzSimmons, N.N. & Greene, J.L. (2001). Demographic and ecological factors affecting conservation and management of the diamondback terrapin (*Malaclemys terrapin*) in South Carolina. *Chelonian Conservation and Biology* 4(4): 66–74.

Haskell, A., Graham, T.E., Griffin, C.R. & Hestbeck, J.B. (1996). Size related survival of head started redbelly turtles (*Pseudemys rubriventris*) in Massachusetts. *Journal of Herpetology* 30(4): 524–527.

Herlands, R., Wood, R., Pritchard, J., Clapp, H. & Le Furge, N. (2004). Diamondback terrapin (*Malaclemys terrapin*) head-starting project in southern New Jersey. In *Conservation and Ecology of Turtles of the Mid-Atlantic Region: A Symposium*. 13–21 pp. Swarth, C.W., Roosenburg, W.M. & Kiviat, E. (Eds.). Bibliomania Publishers. Salt Lake City, Utah. ISBN: 978-1932871012.

Holliday, D.K., Elskus, A.A. & Roosenburg, W.M. (2009). Impacts of multiple stressors on growth and metabolic rate of *Malaclemys terrapin*. *Environmental Toxicology and Chemistry: An International Journal* 28(2): 338–345.

IUCN (2024). The IUCN Red List of Threatened Species. Version 16 (March, 2024). https://www.iucnredlist.org.

Koper, N. & Brooks, R.J. (2000). Environmental constraints on growth of painted turtles (*Chrysemys picta*) in northern climates. *Herpetologica* 56(4): 421–432.

Rowe, C.L. (2018). Standard metabolic rates of early life stages of the diamondback terrapin (*Malaclemys terrapin*), an estuarine turtle, suggest correlates between life history changes and the metabolic economy of hatchlings. *Zoology* 127: 20–26.

Rowe, C.L., Liang, D. & Woodland, R.J. (2020). Effects of constant and fluctuating incubation temperatures on hatching success and hatchling traits in the diamondback terrapin (*Malaclemys terrapin*) in the context of global warming. *Journal of Thermal Biology* 88: 102528.

Silliman, B.R. & Bertness, M.D. (2002). A trophic cascade regulates salt marsh primary production. *Proceedings of the National Academy of Science* 99(16): 10500–10505.

Szerlag-Egger, S. & McRobert, S.P. (2007). Northern diamondback terrapin occurrence, movement, and nesting activity along a salt marsh access road. *Chelonian Conservation and Biology* 6(2): 295–301.

Wood, R.C. (1997). The impact of commercial crab traps on northern diamondback terrapins, *Malaclemys terrapin terrapin*. In *Proceedings: Conservation, Restoration, and Management of Tortoises and Turtles—An International Conference*. 21–27 pp. New York: New York Turtle and Tortoise Society.

Woodland, R.J., Rowe, C.L. & Henry, P.F.P. (2017). Changes in habitat availability for multiple life stages of diamondback terrapins (*Malaclemys terrapin*) in Chesapeake Bay in response to sea level rise. *Estuaries and Coasts* 40: 1502–1515.

Accepted: 8 July 2024